

OBSERVATION OF AN ENHANCED LAMB DIP WITH A PURE Xe

GAIN CELL INSIDE A 3.5μ He-Xe LASER*

by

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ABSTRACT

The observation of an enhanced Lamb dip is reported for a pure Xe^{136} gain tube in a He-Xe^{136} laser cavity. The pure Xe gain cell is operated at a pressure of 5 mTorr so that pressure broadening effects are negligible. The observed enhanced Lamb dip has a 5 MHz width and a depth which is 10% of the peak power. It is estimated that frequency stabilization at 3.5μ to one part in 10^{11} is possible using the enhanced Lamb dip as a reference.

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Observation of an inverted Lamb dip due to an absorbing cell inside the laser cavity has been reported previously,¹⁻³ and it has been suggested that the inverted dip may be used for frequency stabilization purposes. In previous experiments, the absorption gas was either an organic compound whose absorption peaks were near the laser frequency or a cell using the same atom as the laser, such as Ne in a He-Ne laser.

We report the first observation of an enhanced Lamb dip in a laser oscillator using an internal gain cell. In our case, the pure Xe tube serves to provide additional gain, instead of loss at the He-Xe 3.5μ transition. With this arrangement, the usual Lamb dip of the He-Xe laser, which operates at a 2 Torr pressure, is enhanced by the narrow Lamb dip of the pure Xe cell which is operated at a pressure of a few millitorr. Thus the Xe gain cell provides a narrow Lamb dip which can be used for a frequency marker while at the same time using the higher output power and gain of the He-Xe laser tube.

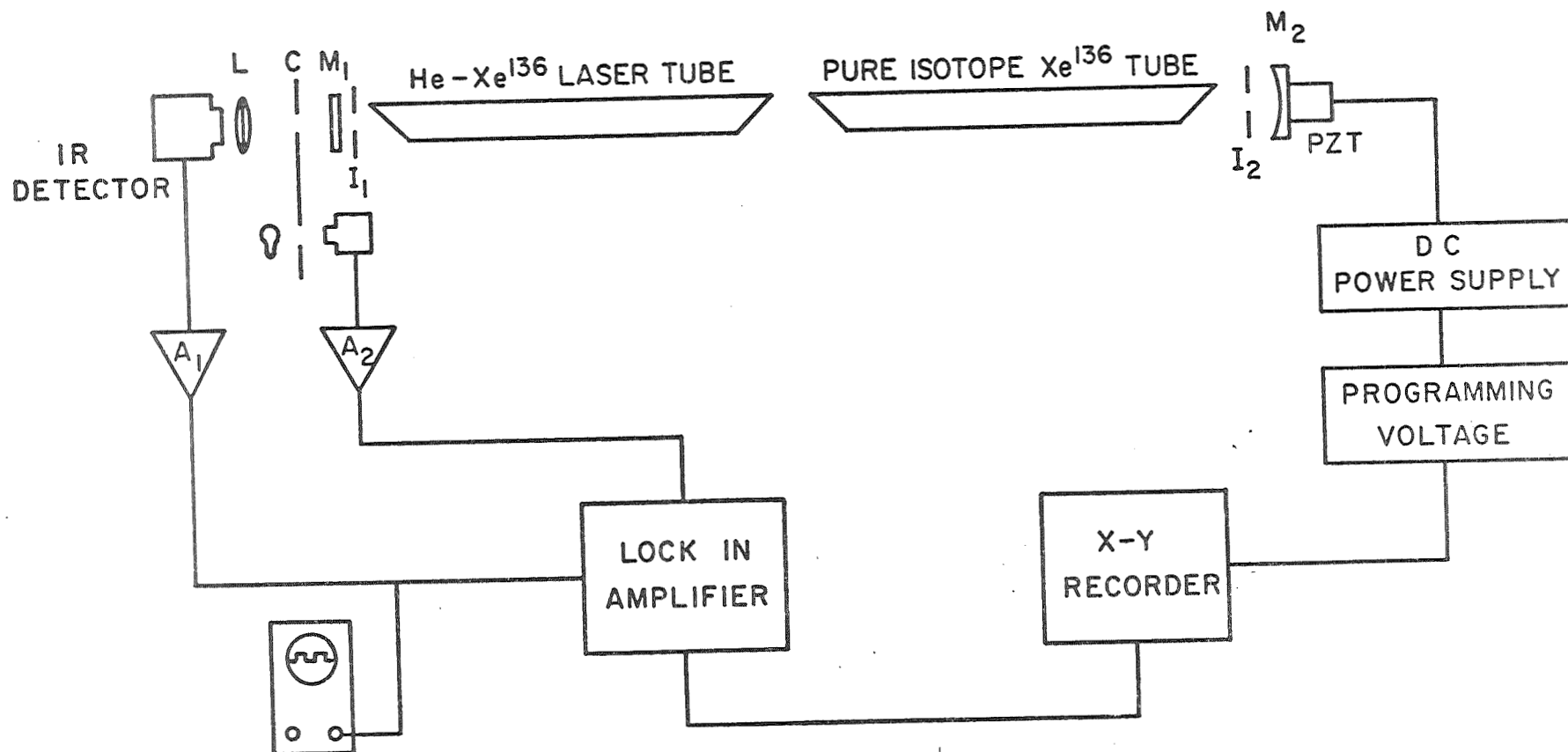
The He-Xe laser used in this experiment is a 20 cm long, 4 mm diameter discharge tube filled with 2 Torr of He and approximately

20 mTorr of single isotope Xe^{136} . The Xe gain cell is a 30 cm long, 6 mm diameter discharge tube filled with isotopic Xe^{136} to a pressure of about 5 mTorr. The Xe pressure in both tubes is controlled by a liquid nitrogen cooled pressure adjustment system. This allows the tubes to be operated over long lifetimes by providing a large reservoir of Xe to counteract the gas clean up problem.

Figure 1 is a block diagram of the experimental set-up. The cavity is 83 cm long with invar bar spacers. The air path of the laser beam inside the cavity is enclosed to avoid any fluctuations due to air motion. The output mirror is a flat with about 50% transmittance and the other mirror is a 400 cm radius of curvature high reflector. Both the He-Xe and the pure Xe tubes are designed for dc and rf excitation. In the present experiment the He-Xe tube was rf excited, while the pure Xe gain cell was both rf and dc excited to maintain a uniform discharge.

The doppler width of the He-Xe laser at 3.5μ is about 110 MHz. Thus the present cavity configuration provides operation on only a single longitudinal mode. Single transverse mode operation was obtained by the use of two apertures inside the laser cavity. A single isotope of Xe was used to eliminate the possibility of an isotope effect on the output power vs. frequency tuning of the laser.

The output power as a function of laser frequency was recorded in two steps. First the curve was taken with the Xe gain cell tube turned off to show the pressure broadened slightly asymmetrical Lamb dip. The curve was then taken with the gain cell discharge on but with the laser output power adjusted to the previous level to avoid power broadening effects. The results are shown in Fig. 2. The dotted portion of the



M₁, M₂ = REFLECTING MIRRORS

I₁, I₂ = IRIS

C = CHOPPER

L = LENS

A₁, A₂ = AMPLIFIERS

FIGURE 1

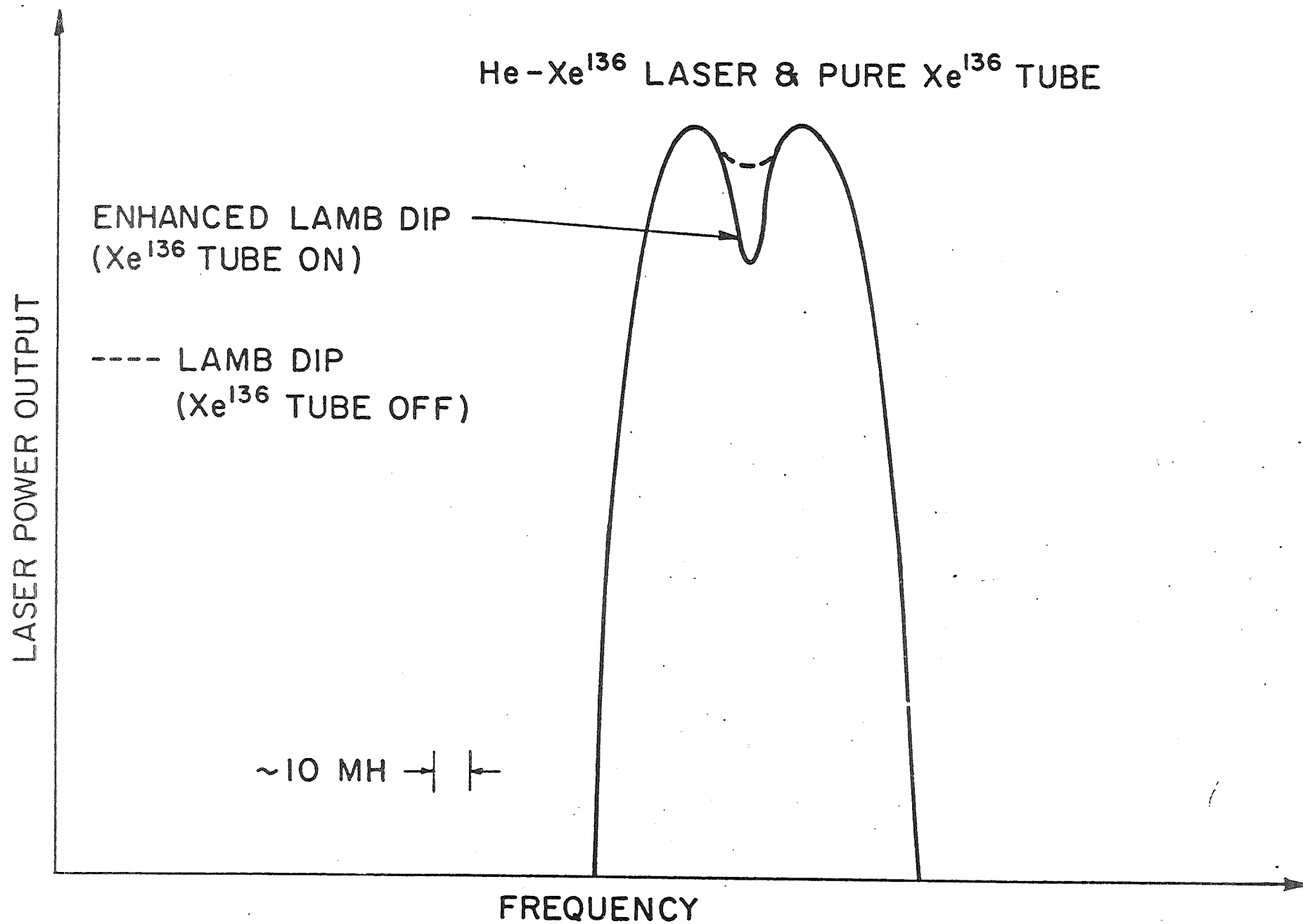


FIGURE 2

curve shows the He-Xe laser output only, and the solid curve shows the enhanced Lamb dip resulting from the Xe gain tube. The curves show that the enhanced dip is narrower than the laser Lamb dip due to the low pressure in the Xe gain cell, and that the enhanced dip is significantly deeper than the laser Lamb dip. For the present case, the width of the enhanced Lamb dip is 5 MHz and the total depth is about 10% of the peak power.

The intensity of the laser as a function of frequency with an additional gain cell or absorption cell inside its cavity can be derived from Lamb's theory⁴ with slight modifications. If we neglect with asymmetry effects due to collisions⁵ we find that

$$I(\Omega) = K_0 \frac{1 \pm K_1 - K_2 e^{(\Omega^2/\Delta\omega_D^2)}}{[1 + \gamma_1^2/(\gamma_1^2 + \Omega^2)] \pm K_3 [1 + \gamma_2^2/(\gamma_2^2 + \Omega^2)]},$$

where K_0 is a constant, and $\Omega = \omega - \omega_0$ is the detuning from line center. $K_1 = G_{20}/G_{10}$, $K_2 = R/G_{10}$, and $K_3 = (G_{20}/G_{10})(I_{s1}/I_{s2})$ are constants relating the unsaturated laser gain G_{10} , unsaturated gain or absorption of the gas cell G_{20} , the cavity loss R , the saturation intensities of the laser tube, and the gain or loss tube I_{s1} and I_{s2} , respectively. γ_1 and γ_2 are the linewidths of the laser and the gain cell and are related to the natural linewidth γ_n and to the collision linewidth γ_c of the transition by $\gamma = \gamma_n + \gamma_c$.

In this expression the numerator is the doppler broadened line shape function with a doppler linewidth $\Delta\omega_D$. The first term in the denominator is the usual laser Lamb dip while the second term is the enhanced Lamb dip

or the inverted Lamb dip, depending on the sign. As can be seen from the expression, the depth of the enhanced Lamb dip depends upon both the relative gains of the two cells and upon their relative saturation parameters. In our present case the total He-Xe laser tube pressure was about 2 Torr, while the pure Xe^{136} tube pressure was 5 mTorr. For these pressures and the excitation conditions we expect that $\gamma_1 \gg \gamma_2$ and that $I_{s1} \gg I_{s2}$. With proper excitation conditions to adjust the relative gain values we, therefore, expect to observe a narrowed enhanced Lamb dip due to the pure Xe gain cell.

The nature linewidth of the Xe atom at 3.51μ is about 2 MHz which can be calculated from the known lifetimes of the upper and lower levels which are 1.36×10^{-6} sec and 4.5×10^{-8} sec, respectively.⁶ The frequency broadening due to collisions is negligible compared to the radiative lifetime in the pure Xe tube. Thus, the enhanced Lamb dip should have a width of twice the natural linewidth.⁷ With possible power broadening of the enhanced Lamb dip taken into consideration, the observed width of 5 MHz is in good agreement with the theoretical prediction.

By using the He-Xe¹³⁶ laser to provide gain and power, and the low pressure pure Xe¹³⁶ tube to provide a narrow frequency discriminant, our present combination scheme should be very useful as a frequency standard in the near infrared. With appropriate feedback control techniques, the frequency of the laser can be stabilized to better than one part in a thousand of the enhanced Lamb dip of 5 MHz, and we thus estimate that for the 3.51μ Xenon laser frequency stabilization to one part in 10^{11} is possible. Furthermore, this technique could easily be extended to other lasers for which low pressure narrow linewidth gain tubes can be constructed.

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FIGURE CAPTIONS

1. A schematic diagram of the enhanced Lamb dip He-Xe¹³⁶ laser with the pure Xe¹³⁶ gain cell. The fill pressure of the He-Xe¹³⁶ laser tube is 2 Torr and the pressure of the Xe¹³⁶ gain cell is about 5 mTorr.
2. The power output vs. frequency tuning curve (solid) show the enhanced Lamb dip observed in He-Xe¹³⁶ laser oscillating at 3.5μ with an excited pure Xe¹³⁶ gain cell inside the cavity. The dotted portion, recorded with Xe¹³⁶ gain cell turned off, was superposed. Only the upper half of the whole power tuning curve is shown here.